Ref. Ares(2017)4764394 - 29/09/2017

HEAT-SHIELD

Integrated inter-sector framework to increase the thermal resilience of European workers in the context of global warming

Deliverable 2.1

Investigation on parameters relevant to vulnerability of workers

Part 1: Individual heat stress responses: An update

Authors: Josh Foster, Simon Hodder and George Havenith

Part 2: Individual Vulnerabilities – translating strain levels between different groups within the population

Authors: George Havenith, Simon Hodder and Josh Foster,

Part 3 Individual vulnerability modelling using thermophysiological models.

Authors: Dusan Fiala and George havenith,

Executive Summary

The main purpose of this report is to consider how the vulnerability of the population, and especially the working population, to climate related heat stress is affected by a number of factors related to the individual's characteristics.

This report consists of three parts. Part 1 provides the outcome of a literature review on individual factors that affect vulnerability to heat stress as a consequence of climate change. The factors considered are: fitness, acclimation, age, body size, body fat, surface area to mass ratio, and gender. Also, given the increase in morbidity due to diabetes, the impact of this disease on heat stress response is considered. Part 2 provides normative data on various groupings discussed in part 1 to allow vulnerability models to be expanded to groups beyond the young healthy male, for which such models are usually developed. Part 3 provides examples of how these individual factors can be incorporated in computer simulation models of human thermoregulation. The latter can be used as one of the approaches to vulnerability modelling.

Part1:

Part 1 focuses on identifying physiological factors of importance for individual work tolerance in the context of occupational health and productivity. A review of the literature identified that the following six main factors should be considered when "heat vulnerability" is to be evaluated: Heat acclimation, fitness, age, gender, body mass, body fat content, and the skin surface area to body mass ratio.

Each factor may be considered independently, but there is also considerable interaction of individual factors with the type of work performed (i.e. fixed or relative exercise) and with environmental parameters (i.e. uncompensable or compensable). If everybody is required to have the same work output (the workload is fixed for all), acclimation, fitness, and body mass are the primary indicators of risk of high body temperature and of high cardiovascular strain, with all three factors having an inverse relation with heat strain. The thermoregulatory benefits of improved fitness and acclimation are lost during uncompensable (i.e. where the body is unable to lose all heat it produces) heat stress, but the reduced cardiovascular strain accompanied with these factors will still have a major impact on work performed in that situation. The impact of individual characteristics on the thermoregulatory and cardiovascular responses for different populations is less clear when people all work at a level that is relative to their own work capacity. However, the reduced sweat gland output in females and older people may increase heat strain over a full working day, compared with young adult males in this condition.

The collated evidence provides information of relevance for physiologists, stakeholders, and policy makers. In light of an increasing global surface temperature, the recommendations made in this report may provide the background information needed to evaluate and address productivity losses induced by heat and develop better mitigating measures. Future research should investigate the heat stress response across a full working day for different populations i.e. fit vs unfit, young vs older, male vs female etc., as so far most research is done for much shorter exposure periods.

Part 2:

In part 2, normative data for each of the identified factors were searched and reviewed, and, where data were found, quantitative values are provided. This was the case for gender, age, and fitness. There is solid existing data to quantify how much work capacity and relative cardiovascular strain are affected by these three parameters. In contrast, the interaction of body characteristics (i.e. size, fat %) and acclimation are less developed in terms of normative data here because they can't predict cardiovascular strain directly (see part 3 for further consideration).
The available normative data on work capacity and relative strain based on workload, $\dot{V}O_{2max}$, and heart rate is also provided.

Data is shown in relation to age groups, based on mean/median values for different age groups, but also the population percentile distribution is provided for $\dot{V}O_{2max}$ / workload in relation to age. We consider that vulnerability models for different subgroups: gender, age, fitness, should include these factors

Part 3

In part 3, we present several algorithms capable of simulating the impact of the earlier identified individual factors. These models integrate the factors of importance for heat balance, including consideration of the factors listed in part 1 and 2. The section builds on the following research performed in 2001:

Havenith, G. (2001). Individualized model of human thermoregulation for the simulation of heat stress response. *Journal of Applied Physiology*, 90(5), 1943-1954.

and the text relates to those summarized in 2016:

Fiala, D., & Havenith, G. (2015). Modelling human heat transfer and temperature regulation. In: The Mechanobiology and Mechanophysiology of Military-Related Injuries (pp. 265-302). Springer International Publishing.

While this section presents the state of the art in terms of individualised modelling, when one combines the knowledge of sections 1, 2 and 3, it is evident that further work is needed in the project to build on this existing knowledge and to provide a complete model of importance for evaluating and identifying individual vulnerability.